ABS/Traction Control

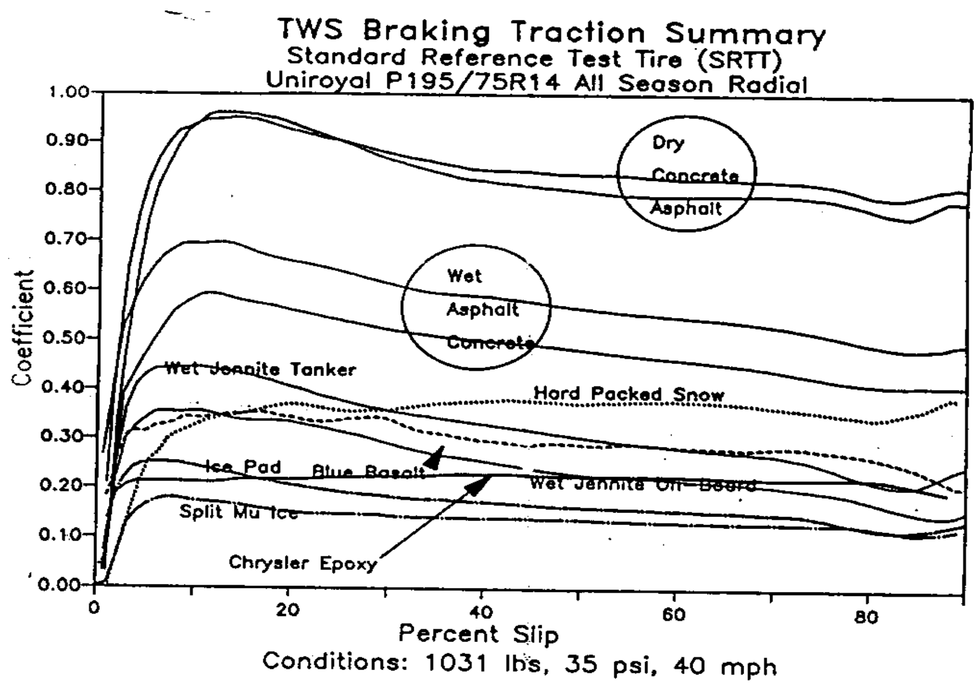
- Introduction
- Modeling (1 wheel)
- Recap on tire-road interface model
- Simple rule-based control
- Modeling (half-car)
- Extension of ABS/TCS

Early Development of ABS

- ABS (Antilock Braking Systems) go back to at least 1908, when J.E. Francis developed a railcar version.
  - To avoid flatspots
  - It is soon noticed trains with ABS stopped faster
- Robert Bosch GmbH received a patent in 1936 for an ABS system.
- In 1948, Boeing B-47 came equipped with an ABS (by Hydro Aire). Control is bang-bang type (dump pressure to zero then rebuild).
- Fully modulating ABS were first developed in the 1950's (Goodyear and Hydro Aire)
  - Ford: 1954 experimental Lincoln
  - Kelsey-Hayes: 1968 rear-wheel only system
  - GM (AC Electronics)" 1971 Olds Toronado rear-wheel only
  - Chrysler (uses Bendix system): 1971 Imperial 4-wheel ABS

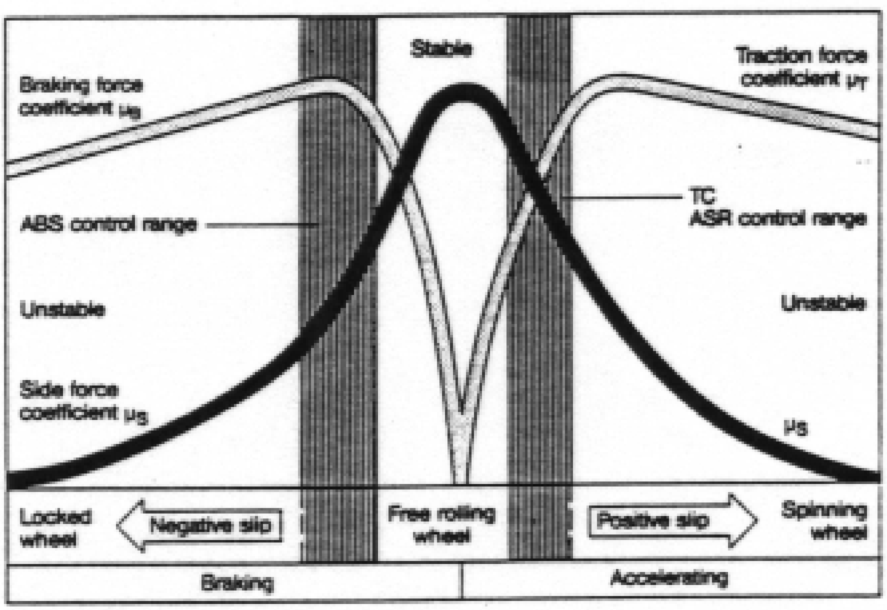
How ABS/TCS works

- ABS (Antilock Braking Systems)
  - Active control of wheel brake pressure when driver braking exceeds the limit of the road
- TCS (Traction Control Systems)
  - Active control of brake pressure and/or engine torque when driver acceleration exceeds the limits of the road



Benefits of ABS/Traction Control

- – Maintain Stability
- – Maintain Steerability
- – Minimize Stopping Distance
- – Reduced Driver Workload



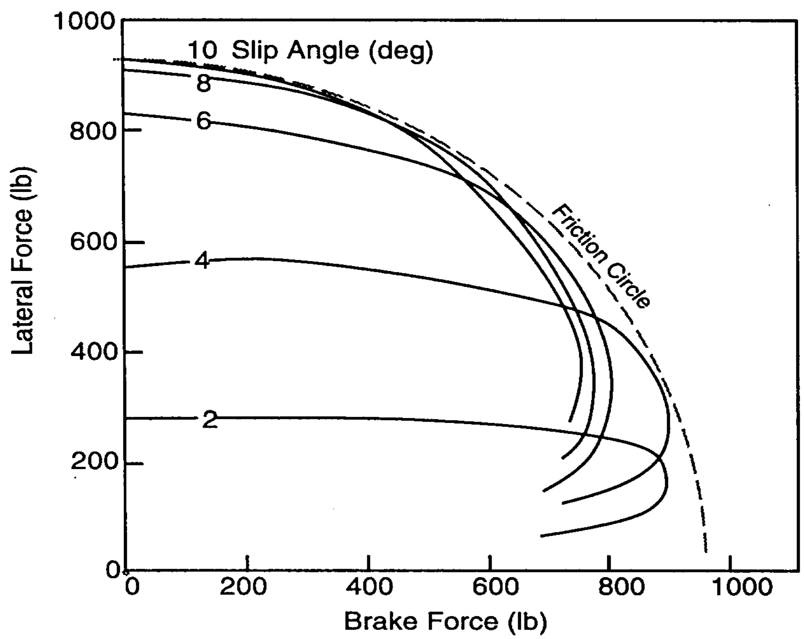
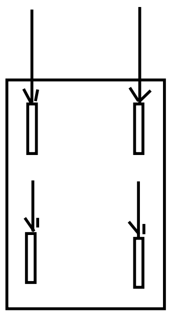


Fig. 10.23 Lateral force versus longitudinal force at constant slip angles.

Vehicle Control Objectives (ABS example)

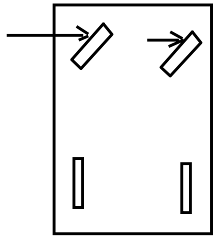
I. Stopping Distance

- Maximize longitudinal forces
  - Find peak
  - Cycle efficiently



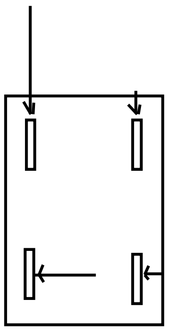
II. Steerability

- Maximize front lateral force capability
- No braking at front



III. Stability - under torque disturbances

- Maximize rear lateral force capability
- No braking at rear



Clearly, there is a trade-off!

One-wheel ABS/TCS Model

$$\dot{\omega}_w = [(T_e - T_b - r_w F_x - T_w(\omega_w)] / J_w$$

$$\dot{u} = [-0.5\rho C_d A(u + u_w)^2 - fmg\cos\Theta - mg\sin\Theta + N_w F_x] / m$$

$$F_X = \mu \ F_Z$$

Input torque (T_e or T_b) changes wheel speed.
Then, wheel slip, μ , Fx and thus vehicle speed is influenced.

A 2-state system can be defined

Unit: rad/sec

$$\dot{x}_1 = [-(0.5\rho C_d A)(r_w x_1 + u_w)^2 - fmg\cos\Theta - mg\sin\Theta + N_w F_z \mu(\lambda)]/(mr_w)$$

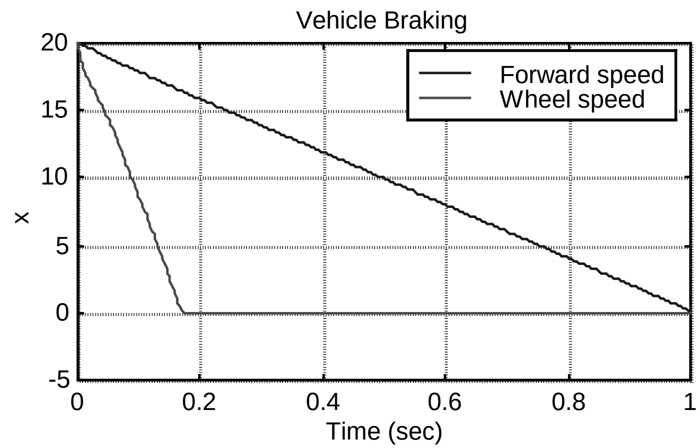
$$\dot{x}_2 = [-f_w F_z - b_w x_2 - F_z r_w \mu(\lambda) + T] / J_w$$

Simplified ABS/TCS control problem: find proper $T=T_e-T_b$ to achieve wheel slip regulation.

Ex8.3 Vehicle Braking Behavior (no ABS)

```
% Ex8_3.m
ti=0.0; tf=1.0; xi=[20.0, 20.0];
tol=1.0e-4; trace=1;
[t,x]=ode45('Ex8_3a',ti,tf,xi,tol,trace);
plot(t,x); title('Vehicle Braking');

% A separate file Ex8_3a.m
function xdot=Ex8_3a(t,x);
% Define the simulation parameters:
m=1400; rho=1.202; Cd=0.5; A=1.95; g=9.81;
Theta=0.0; bw=0.0; f=0.01; uw=0.0; fw=0.0;
Iw=2.65; rw=0.31; Nw=4; Fz=3560.0;
% Define the mu-lambda polynomial coefficients:
c=[-68.593, 238.216,-324.819,219.283,
    -75.58,  12.088, -0.0068];
if x(1) >= x(2),
   lambda=(x(2)-x(1))/x(1);
else
   lambda=(x(2)-x(1))/x(2);
end;
al = abs(lambda);
if al > 1.0, al =1.0; end;
mu=sign(lambda)*c*[al^6;al^5; ...
   al^4;al^3;al^2;al;1];
% Define the torque input T = Te - Tb;
Te =0.0; Tb=1000.0;
T = Te - Tb;
% Define the state equations:
if x(1) < 0.0, x(1) = 0.0; end;
if x(2) < 0.0, x(2) = 0.0; end;
xdot=[(-(0.5*rho*Cd*A)*(uw+rw*x(1))^2+
     Nw*Fz*mu-f*m*g*cos(Theta)-
     m*g*sin(Theta))/(m*rw);
      (fw*Fz-bw*x(2)-Fz*rw*mu+T)/Iw];
if x(1) <= 0.0, xdot(1)=0.0; end;
if x(2) <= 0.0, xdot(2)=0.0; end;
```



Rule-based ABS/TCS Control

ABS/TCS algorithms are commonly used in production Vehicles. For example

if wheel slip too large, release
if wheel slip too small, reapply
else, hold the pressure

DT = 0.0

IF $\omega_w > \omega_v$ THEN $\lambda = \dfrac{\omega_w - \omega_v}{\omega_w}$ ELSE $\lambda = \dfrac{\omega_w - \omega_v}{\omega_v}$ END

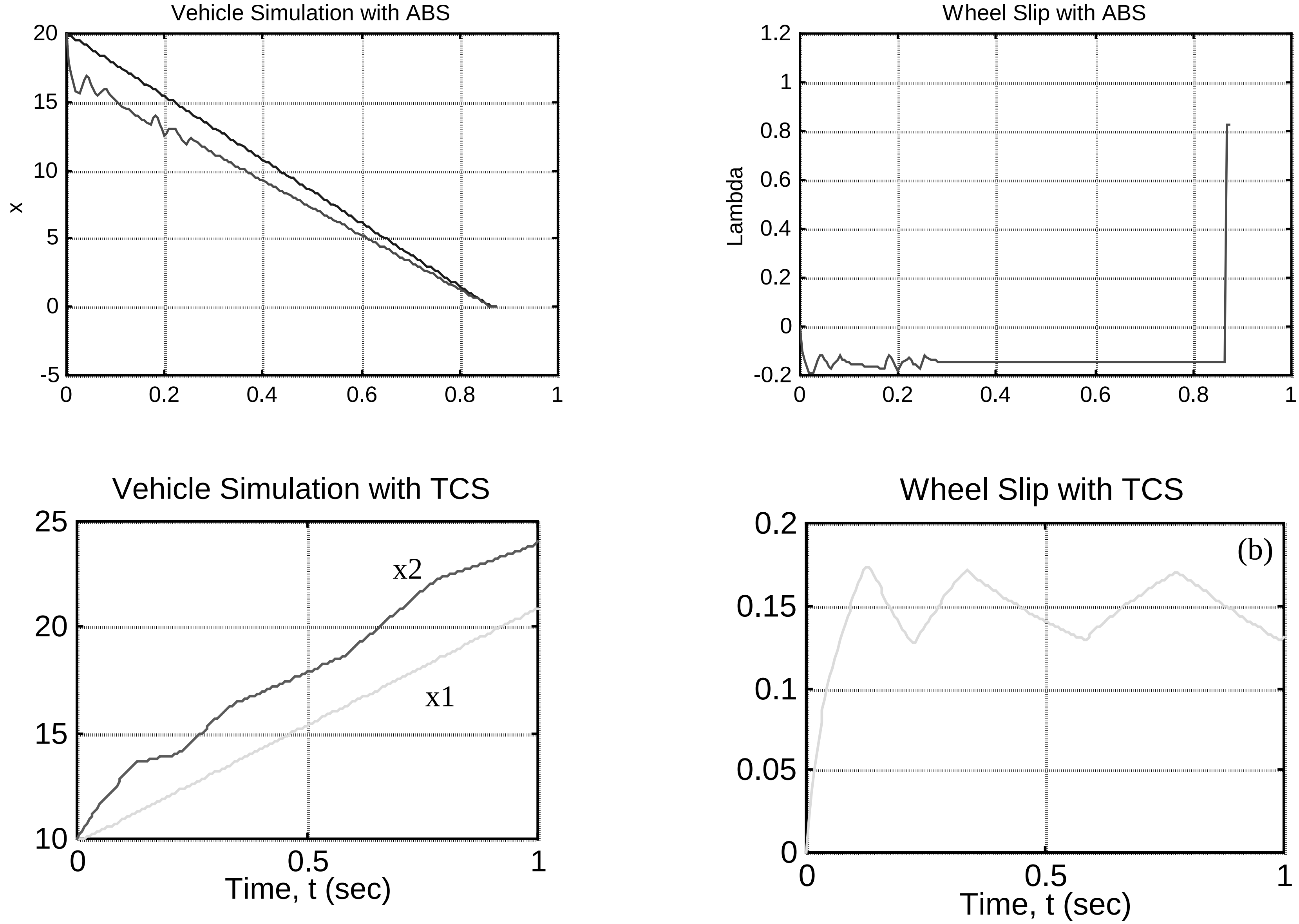
IF $|\lambda(t)| < \lambda_{\min}$ THEN DT = sgn(λ) α_1 |T(t-1)| END

IF $|\lambda(t)| > \lambda_{\max}$ THEN DT = -sgn(λ) α_2 |T(t-1)| END

T(t) = T(t-1) + DT

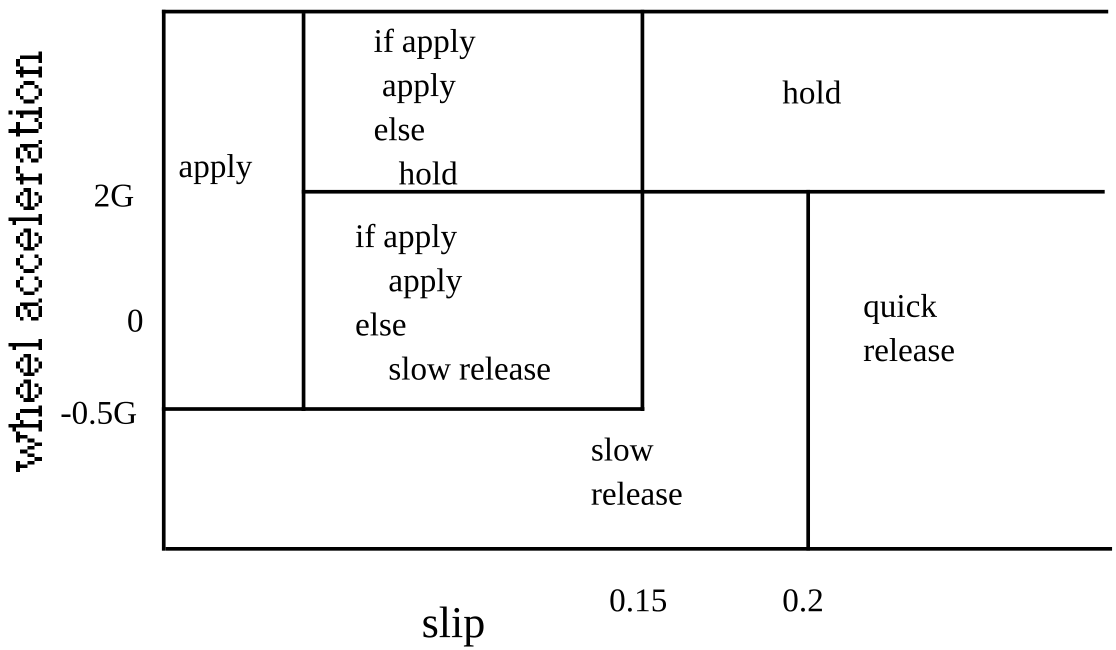
What can be improved?

Ex8.5 and Ex8.6--Rule based ABS and TCS



Rules in Real Production ABS/TCS can be A Lot More Complicated

- Figure out “reference speed”
- Calculate slip based on the reference speed signal
- Wheel acceleration indicates whether wheel speed is recovering.



Half-car ABS/TCS Model

$$F_{zf} = \frac{bmg}{a+b} + \frac{(F_{xr} + F_{xf})h}{a+b}$$

$$F_{zr} = \frac{amg}{a+b} - \frac{(F_{xr} + F_{xf})h}{a+b}$$

$$F_x = \mu \ F_z$$

$$\Rightarrow \begin{bmatrix} a+b-\mu_f h & -\mu_f h \\ \mu_r h & a+b+\mu_r h \end{bmatrix} \begin{bmatrix} F_{xf} \\ F_{xr} \end{bmatrix} = \begin{bmatrix} bmg\mu_f \\ amg\mu_r \end{bmatrix}$$

Real-World Performance of ABS Systems

- NHTSA (1994,1995)--Increase in fatal single vehicle crashes.

  Significant (~40%) increase in rollover crashes (passenger cars).

- GM (1995, 1996)--Slight increase in overall crashes

  Significant (~40%) increase in rollover crashes.

- FAA (1996)--Significant decrease in overall crashes

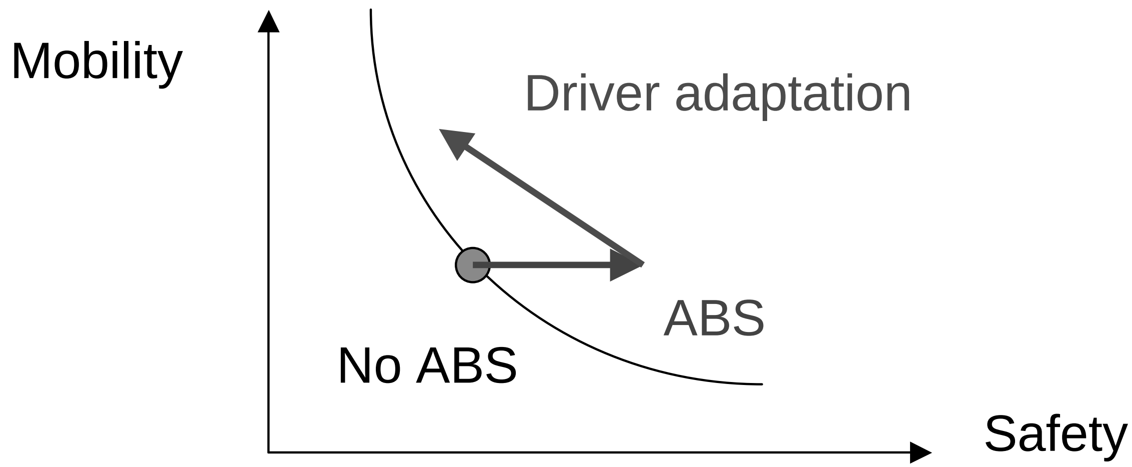
  No change in fatal crashes

- IIHS (1996)--Decrease in multiple-vehicle crashes

  Increase in single-vehicle crashes (rollover)

Lessons Learned from ABS Implementation

- It takes a long time for drivers to learn/adapt to vehicles with ABS.
- Adapted driver may develop more aggressive driving behavior.

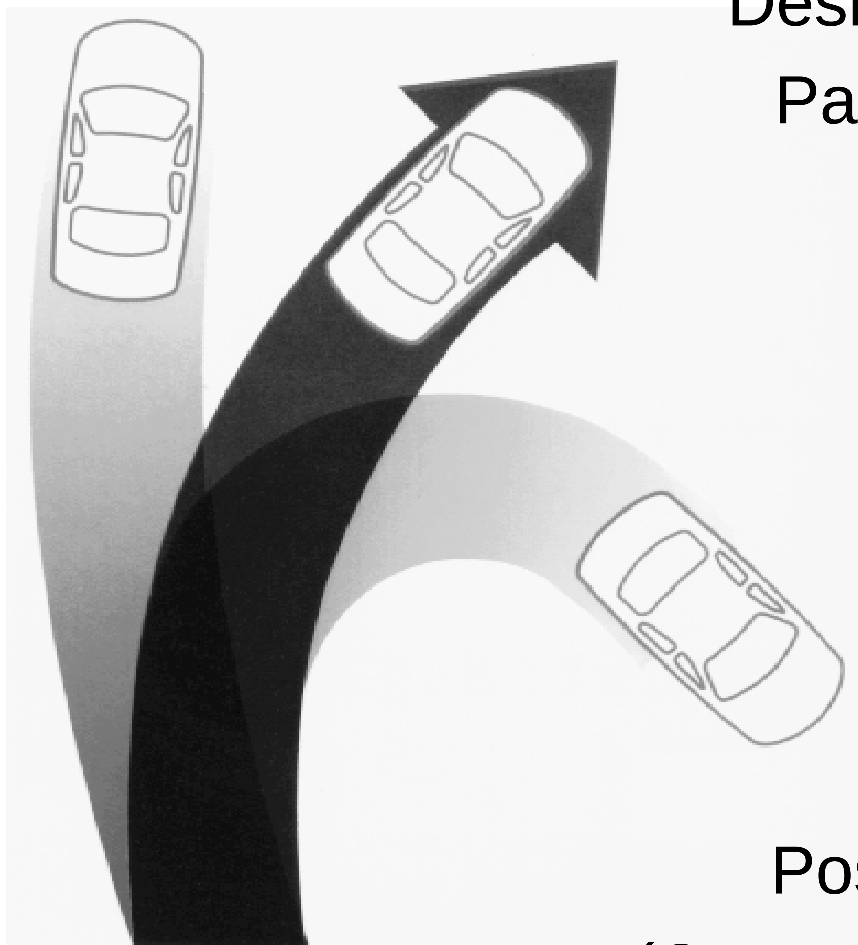


- Improper steering converts one type of crash (collision) into another (rollover).
- Fear of Litigation/Liability issues is the main drag.

Extension of ABS/TCS Functions--Vehicle Dynamics Control

Possible Path
(Understeer/Plow)

Desired
Path

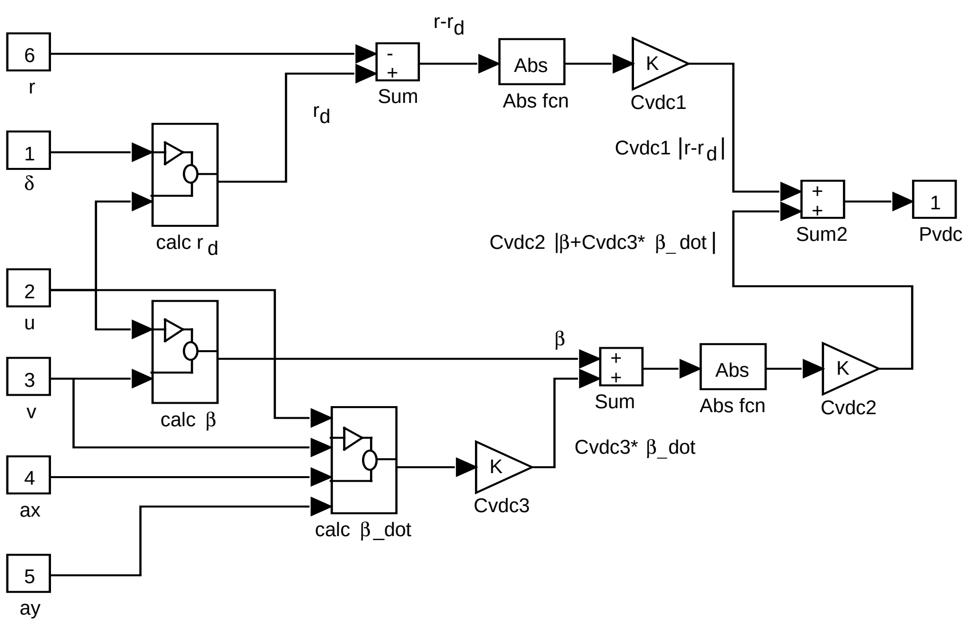


Possible Path
(Oversteer/Looseness)

VDC--How does it work?

VDC-Vehicle Dynamics Control -

Calculate a driver commanded yaw rate which is the yaw rate for the car for a given steer angle and vehicle speed on dry asphalt.
Detect an error between the driver command and the actual vehicle yaw rate.
The torque input is typically done by applying the front brake in the desired vehicle direction.



Desired yaw rate

$$r_d = \frac{u \cdot \delta}{L(1 + \frac{u^2}{V_{ch}^2})}$$

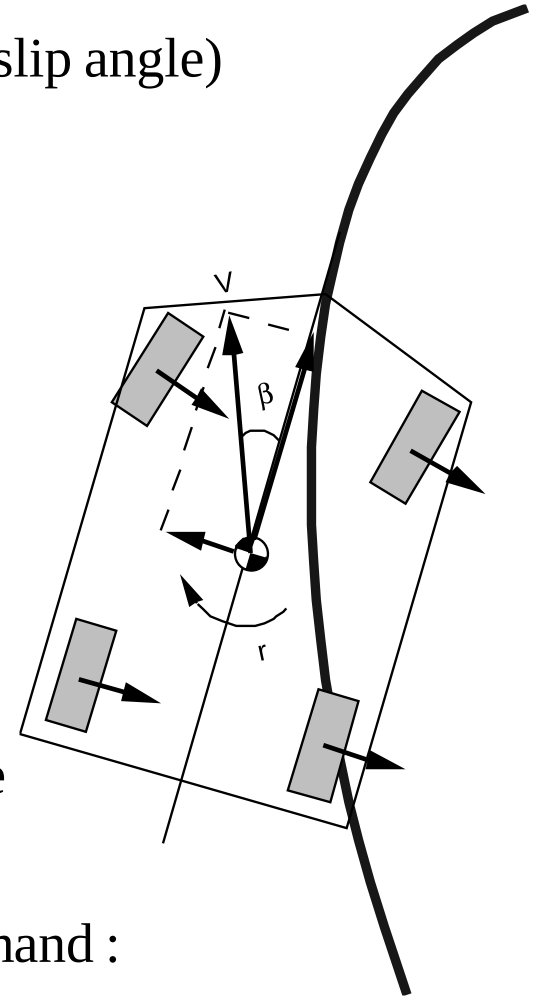
VDC algorithm

$$\Delta P_{VDC} = C_{VDC1}\left|r - r_d\right| + C_{VDC2}\left|\beta + C_{VDC3}\dot{\beta}\right|$$

Desired Yaw Rate?

Recall: $r = \dot{\psi}$ (yaw velocity), $u = rR$, $\beta = \dfrac{v}{u}$ (sideslip angle)

$$\delta_{\mathrm{f}} = \frac{L}{R} + K_{us}\frac{u^2}{R} \Rightarrow R = \frac{L + K_{us}u^2}{\delta_{\mathrm{f}}}$$



Performing simple calculations we get:

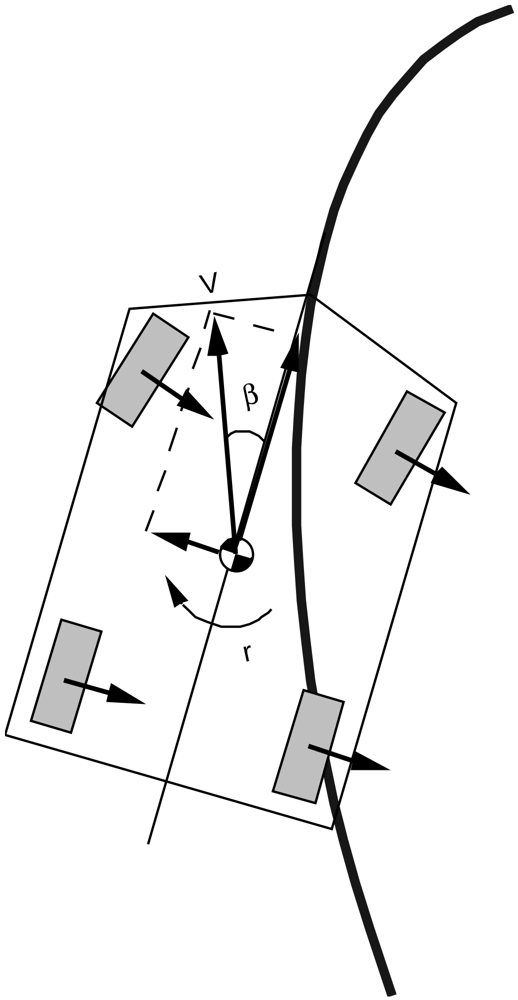
$$r = \frac{u}{R} = \frac{u\delta_f}{L + K_{us}u^2} = \frac{u\delta_f}{L\left(1 + \dfrac{u^2}{L/K_{us}}\right)}$$

Choosing $L/K_{us} = V_{ch}^2$ some characteristic positive number that results in good handling properties we define the desired yaw rate based on the steering comand :

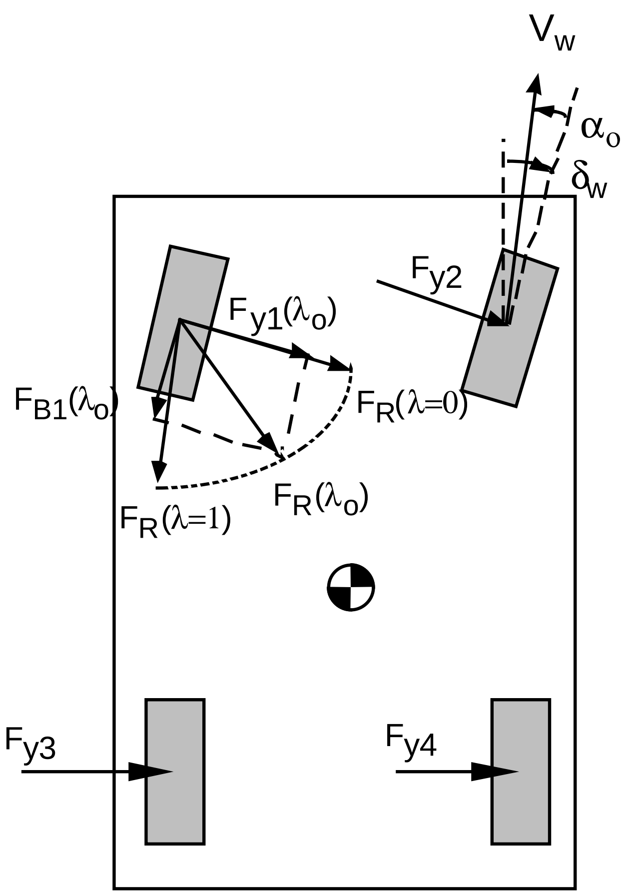
$$r_{des} = \frac{u\delta_f}{L\left(1 + \dfrac{u^2}{V_{ch}^2}\right)}$$

Principles of Vehicle Dynamics Control Systems

- What are VDC systems for?

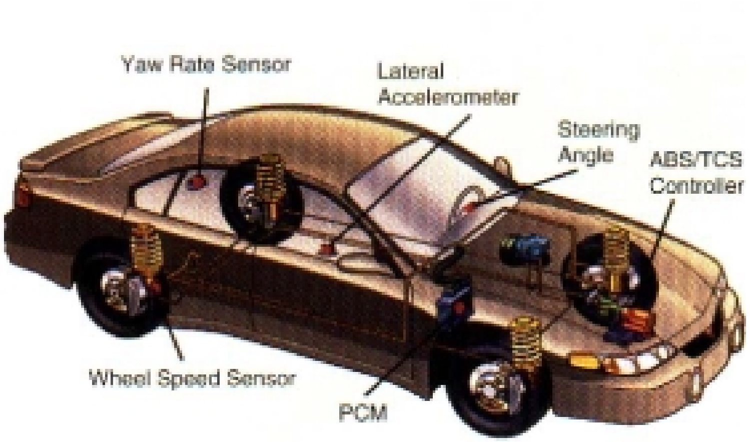


- How do VDC systems work?

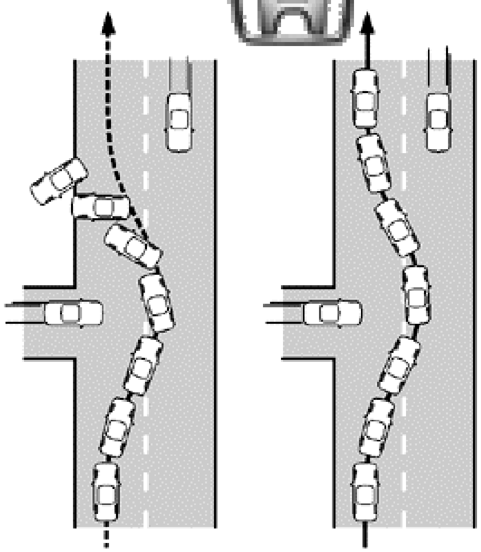


Example VDC Systems

2000 Pontiac Bonneville



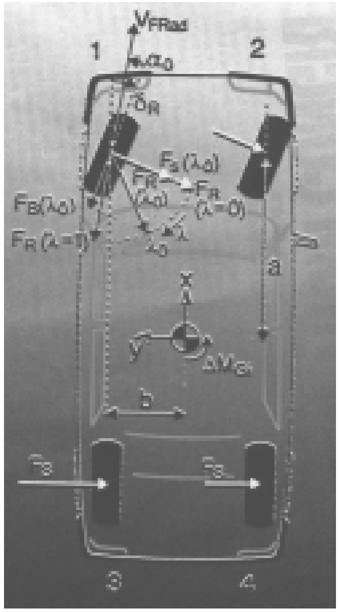
Stabilitrak Control Chassis



Without VDC

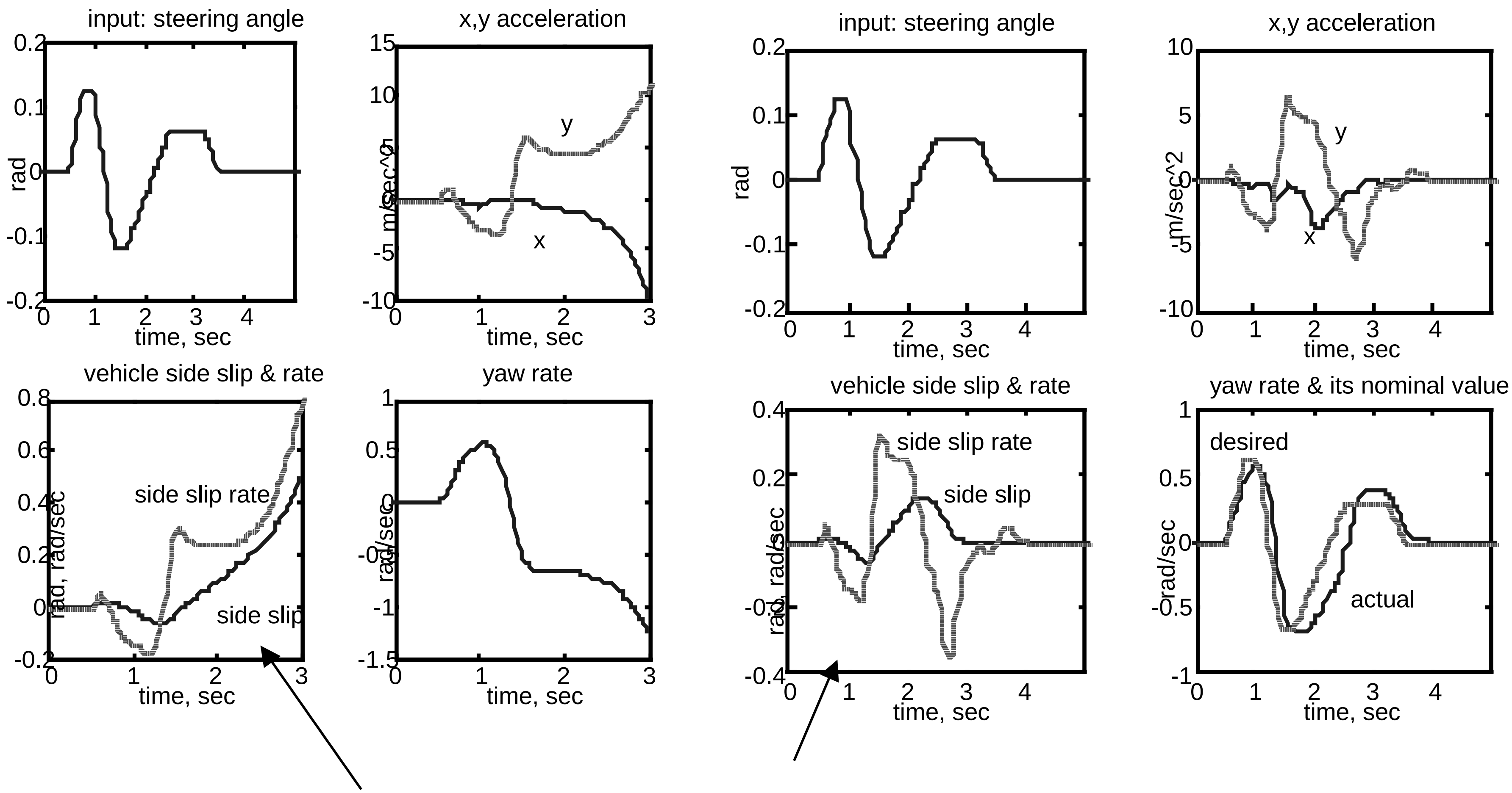
With VDC

Bosch



VDC Verification (step steering with braking)

without VDC **with VDC**



Side slip angle and angular rate